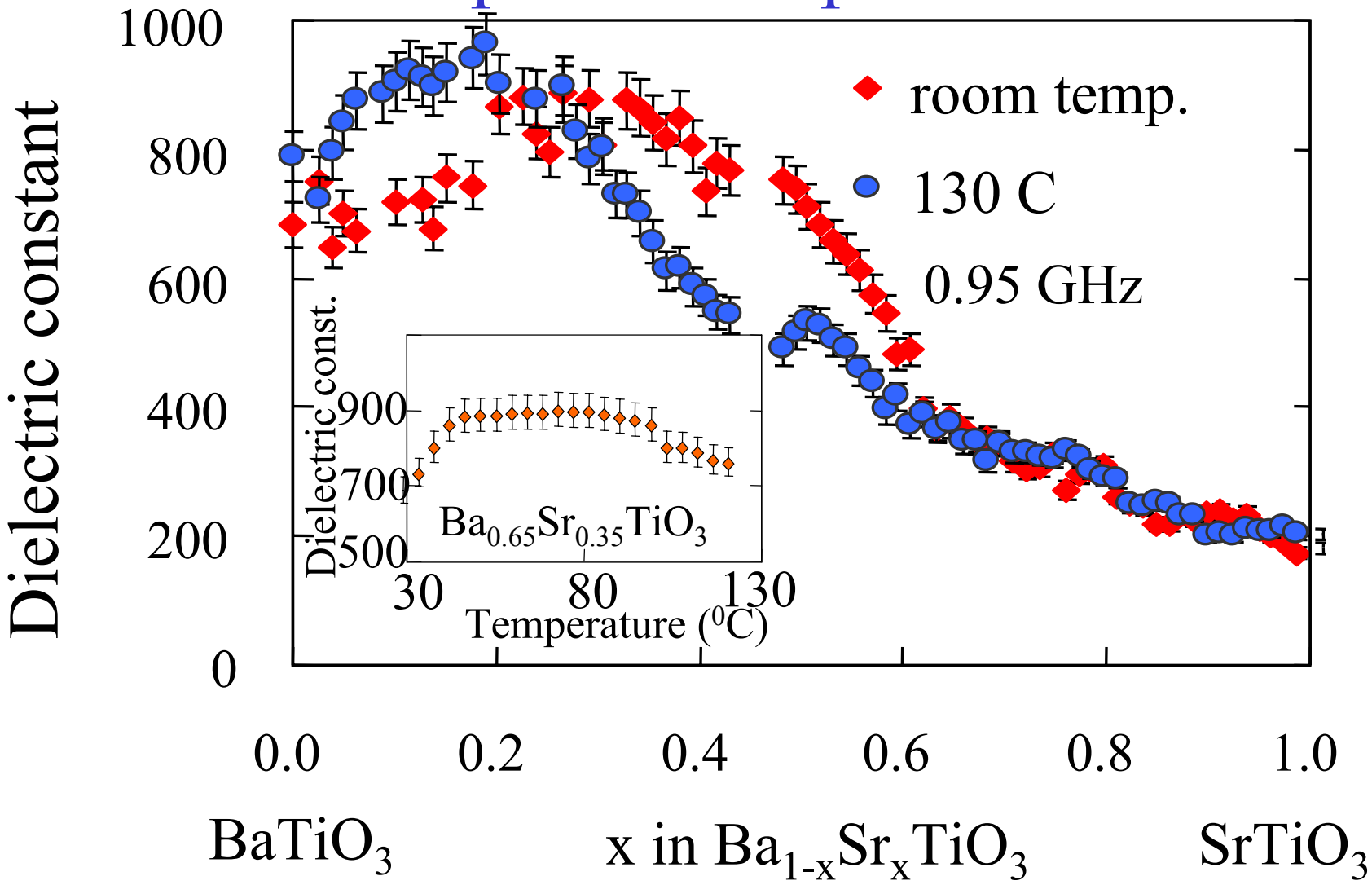
Dielectric constant vs composition: temperature dependence



At the University of Maryland, Ichiro Takeuchi is developing high-throughput techniques for rapidly and systematically mapping the composition-property relationships in a variety of metal oxide thin film systems (NSF DMR0094265). In one approach, the combinatorial pulsed laser deposition system is used to fabricate in-situ deposited epitaxial composition spreads. Various non-destructive characterization tools are used for quantitative physical property mapping of the spreads. The figures are from measurements on a BaTiO3-SrTiO3 continuous composition spread. A multimode variable temperature scanning microwave microscope developed in our lab was used to map the dielectric properties at microwave frequencies. The ability to rapidly map a physical property in a multi-dimensional parameter space (in this case, the parameters are composition, temperature and frequency) using high quality samples is expected to play an important role in the future of materials science. The first figure demonstrates non-destructive variable temperature measurements on the spread. The second figure is the plot of the normalized frequency dispersion versus composition (Appl. Phys. Lett. 79, 4411 (2001)).

It was not clear what the origin of this dispersion behavior in BaTiO3-SrTiO3 was. This has motivated us to pursue extensive broadband measurements of individual composition films in this material system. This was performed in collaboration with James Booth at NIST in Boulder. The studies have revealed that dielectric properties in the GHz (microwave) range are directly affected by the temperature dependent softening/hardening of the phonon soft-mode in the THz range. This is reflected in the composition spread data shown in the second figure: the closer the composition is to the Curie temperature, the lower the frequency of the soft mode is, and consequently, the higher the dielectric dispersion is in the microwave range. Thus, for the first time, the direct influence of the phonon soft-mode on the microwave properties of ferroelectric thin-films has been observed. This has strong implications for device applications of (Ba,Sr)TiO3 at microwave frequencies. Applications of (Ba,Sr)TiO3 thin films are being pursued worldwide for devices such as capacitors in the next generation DRAMS (dynamic random access memories) and tunable microwave communication devices (e.g. tunable filters). High frequency dispersion in dielectric properties means higher dielectric loss (dissipation) and undesirable change in the dielectric constant as a function of frequency. Thus, frequency dispersion may seriously undermine performance of certain devices unless it is better understood and compensated.

Dielectric frequency dispersion vs composition